Implementation of 3D Angular Selective Achromatic Diffraction Optical Grating device

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Abstract: Angular Selective Achromatic Diffraction Optical Grating (ASADOG) device has been implemented. Surface reflective grating had 1200 lines per mm. Two identical volume holograms were implemented using Photo-Thermo-Refractive (PTR) glass technology, with spatial frequency 1697 lines per mm. Sequential diffraction of incident light by surface grating, by first volume grating and then by second one oriented at 90 degrees resulted in angular selection of incident beam, completely achromatic within the spectral range from red to blue including.

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OCIS codes: (050.7330) Volume holographic Gratings

1. Introduction

Filtering of narrow angular component of incident light is a necessary function in numerous optical devices, including lasers, star tracking in orientation systems etc. Simplest design is an aberration-less mirror or lens that focuses incident light, and a pinhole to select the necessary direction. High concentration of energy may hurt the device in laser applications. Other possible device is a volume holographic grating, or a pair of them for 3-D angular selection. However, volume gratings may trade the angle to the wavelength, and thus are applicable for monochromatic beams only.

2. ASADOG device.

We report in this talk the implementation of 3-D angular selection device. The idea of the device's performance is based on the combination of spectrally-dispersive action of surface grating (Edmund reflection grating, $f_s = 1200$ lines/mm in our case) with two volume diffraction gratings positioned in sequence, and possessing spatial frequency $f_{vol} = f_s \cdot \text{sqrt}(2) = 1697$ lines/mm. Fringes of each volume hologram were normal to the surfaces of the plates. Positioning the fringes of the first hologram at 45 degrees to the grooves of surface grating and the grooves of second hologram at 90 degrees to those of the first hologram resulted in the following. Out of all angular components of the incident wide-angle polychromatic beam, only components propagating exactly at a normal to all 5 surfaces of the device satisfied Bragg condition in both holograms and thus were efficiently diffracted and selected. Volume holograms used were prepared by the process of UV recording in Photo-Thermo-Refractive glass, and had thickness 1.28 mm. Angular selectivity with respect to both angular coordinates was better than 2 mrad.

Figure. The beams diffracted on the first Bragg grating appear in the direction perpendicular to the diffraction plane of the surface grating (bottom part of the photo).

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Implementation of 3D ASADOG:
Angular Selective Achromatic Diffraction Optical Grating device

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Overview

Introduction: Angular selective devices, a.k.a. spatial filters

Principles of particular devices:
- ASADOG for angular selection in one direction (1-d)
- ASADOG for angular selection in both directions (2-d)

Tolerances and how to make the device
a. Auto-collimating procedure of recording
b. Inequality for the period of volume grating
c. 2-d via two fixed volume gratings with adjustable angle

Implementation via Photo-Thermo-Refractive recording in glass

Conclusion

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Angular selection devices

Spatial filtering with **pinhole** is achromatic.

Drawbacks:

- **May require vacuum chamber to eliminate breakdown at the focus.**

- **Requires large length or aspherical optics to overcome spherical aberration;**

- **Chromatic aberration may still be a problem.**
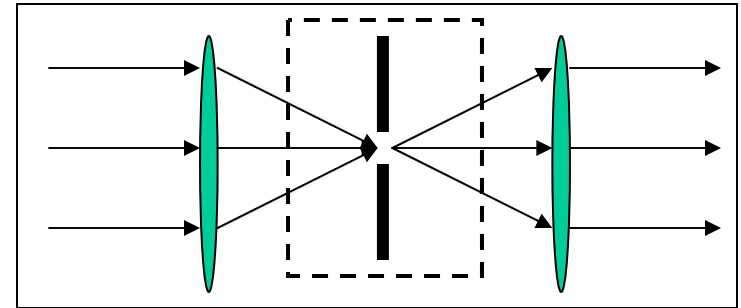
Volume diffraction grating possesses good angular selectivity.

Drawbacks:

Works properly for a fixed wavelength only.

Trades angle θ to the wavelength λ:

diffraction efficiency $\eta = F(\alpha \cdot \theta - \beta \cdot \lambda)$.
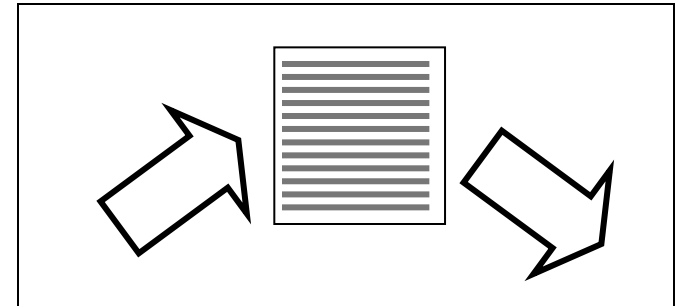
Our recent device, ASADOG, has been implemented

(Angular Selective Achromatic Diffraction Optical Grating).
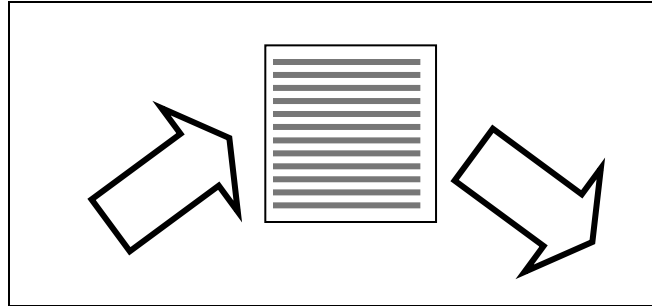
Towards the basic idea of the device

1. Surface diffraction grating does not have any
selectivity, but possesses dispersive power:
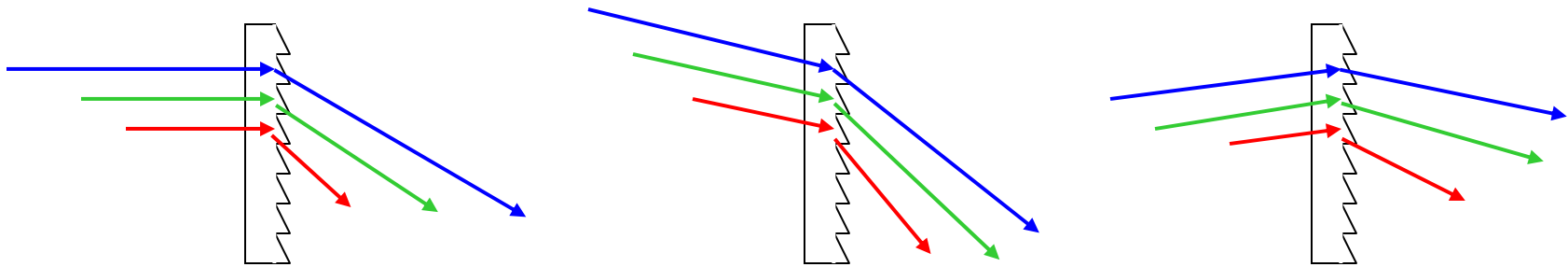
whatever is the direction or color of incident light,
there will be corresponding direction of diffracted beam,
while the diffraction angle depends on the wavelength.

Towards the basic idea of the device

2. Volume diffraction grating possesses both,
<u>Angular selectivity</u> and <u>Spectral selectivity</u>.
However, one property may be traded for the other one.
Namely, diffraction efficiency η depends on the
incidence angle θ and on the wavelength λ in a manner
$$\eta = \eta(c_1\lambda - c_2\theta)$$

Basic idea of the ASADOG device

(Angular Selective Achromatic Diffraction Optical Grating)

Let us combine:

surface diffraction grating, with the period Λ_{surf} ,
and
volume diffraction grating, with the period Λ_{vol}.

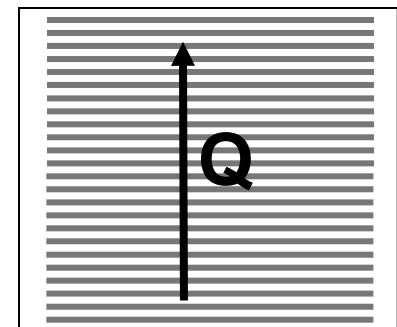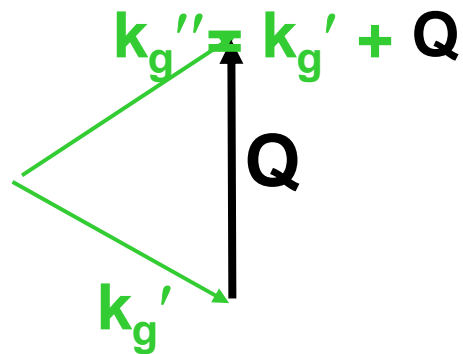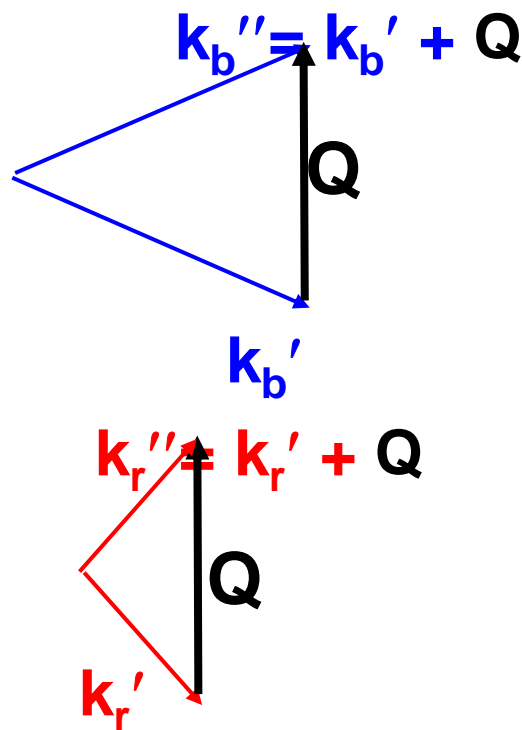Let us require also that

$$\Lambda_{surf} = 2\Lambda_{vol}$$
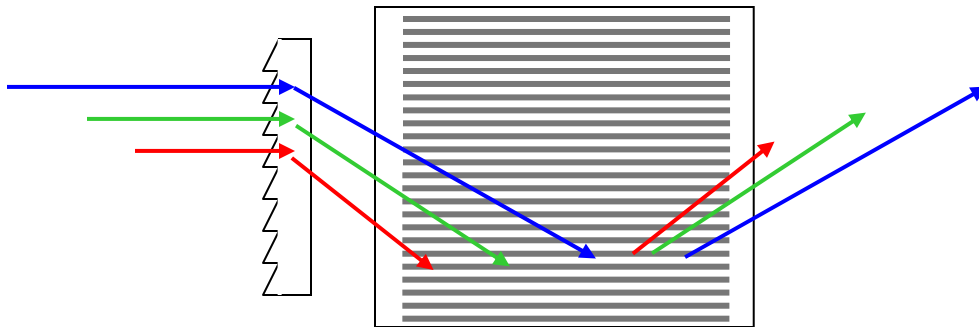
Then all normally incident waves of all colors satisfy Bragg condition for the volume diffraction.
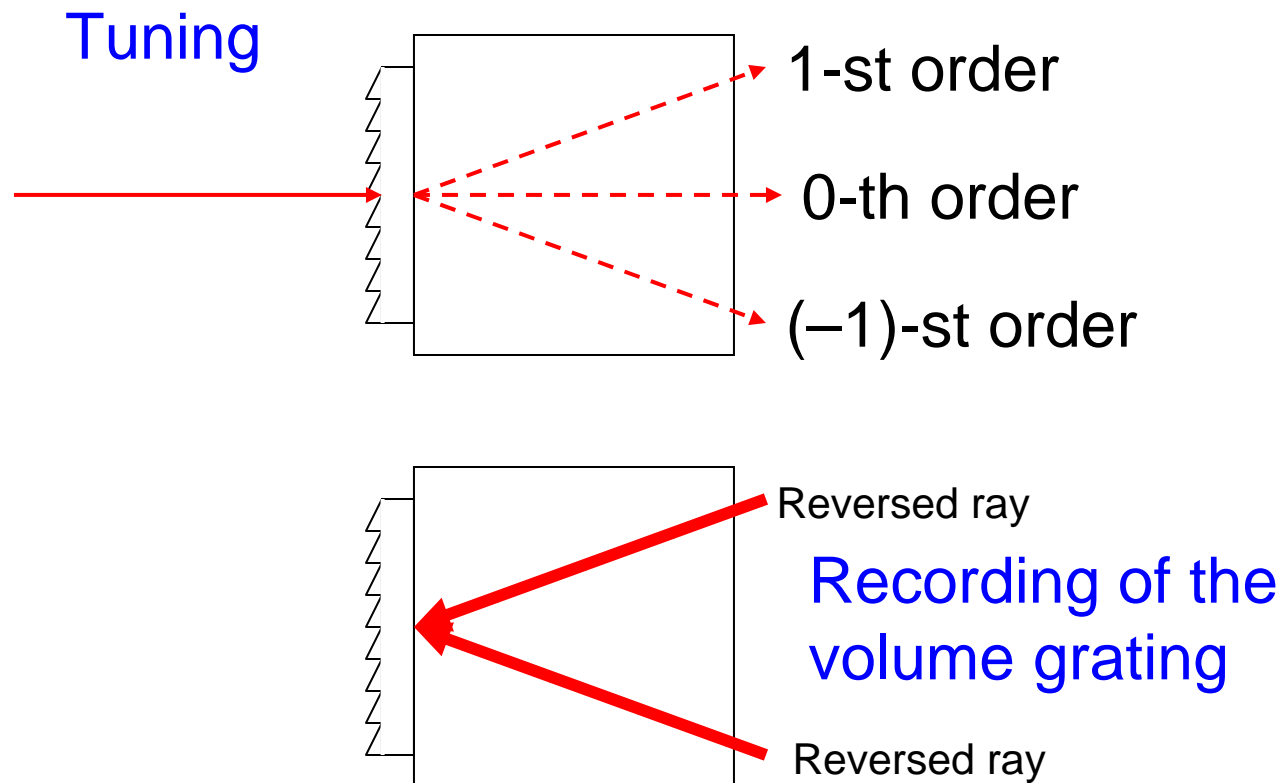
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Proof of the Bragg condition for all colors

$$k_b' = k_b + q$$
$$k_g' = k_g + q$$
$$k_r' = k_r + q$$

$$|q| = 2\pi / \Lambda_{surf}$$

$$Q = -2q, \quad |Q| = 2\pi / \Lambda_{vol}$$

$$k_b'' = k_b' + Q$$

$$Q$$

$$k_b'$$

$$k_g'' = k_g' + Q$$

$$Q$$

$$k_g'$$

$$Q$$

$$k_r'' = k_r' + Q$$

$$Q$$

$$k_r'$$
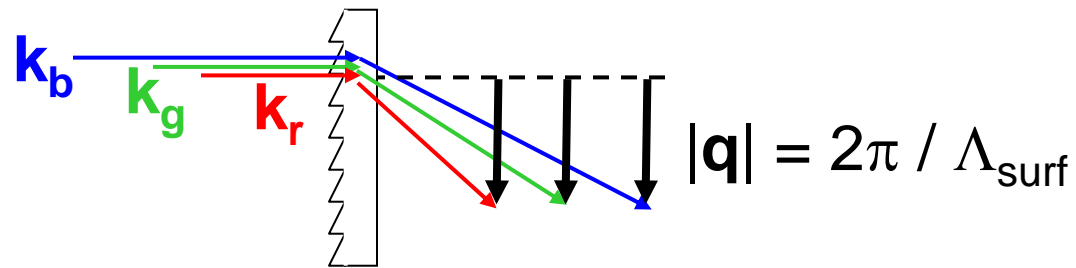
Symmetric configuration guarantees that **k″** has the same length as **k′**, and hence Bragg condition is satisfied.

Auto-collimating procedure
to record $\Lambda_v = \Lambda_s/2$.

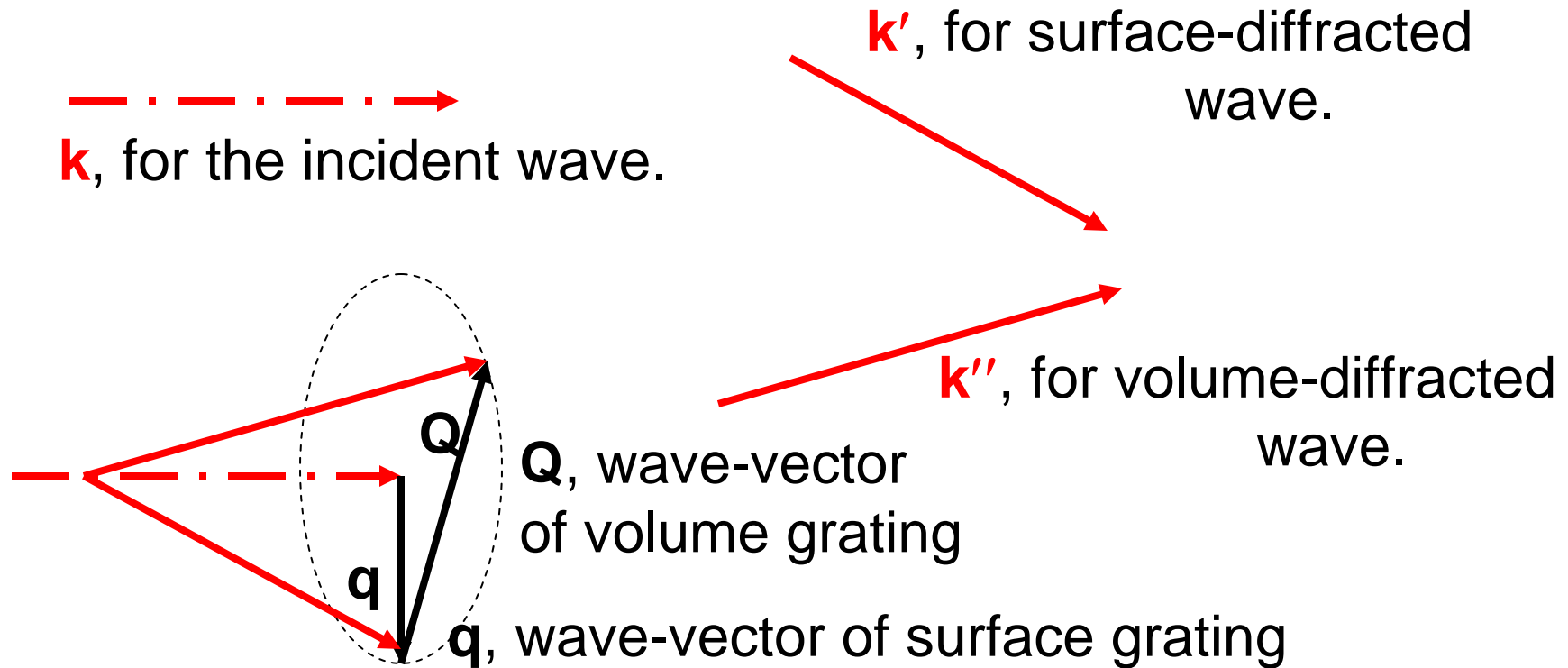# What is important
and what is not
(we understood it only in the process of actualiy making the device)

It is important that the **volume fringes are vertical**.

It is important that the **volume fringes have $Q_v \leq 2q_s$**.

It is not so important that
the volume fringes have $Q_v = 2q_s$ exactly.
One can satisfy Bragg condition
by azimuthal adjustment of surface grating
with respect to volume grating.

Geometry of wave-vectors

k′, for surface-diffracted wave.

k, for the incident wave.

k″, for volume-diffracted wave.

Q, wave-vector of volume grating

q, wave-vector of surface grating

If the end of the vector **Q** lies on the circle of radius |**q**|, and the circle's plane is perpendicular to **k**$_{inc}$, then Bragg condition is satisfied for any color.

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Selection in both angular directions
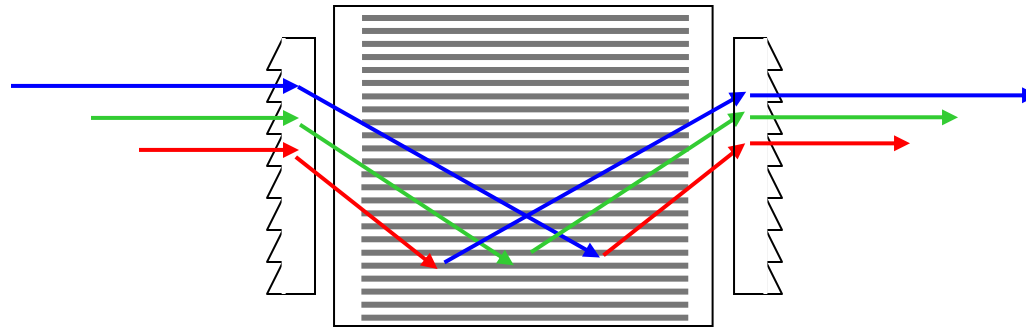
Angular selection by a volume grating discriminates those directions only, which are along the **Q**-vector of the grating.

We use two volume gratings in a sequence, with non-collinear vectors **Q₁** and **Q₂**. We actually made them perpendicular, but this may be somewhat disadvantageous.

$\mathbf{Q}_2$, wave-vector of the 2-nd volume grating

$\mathbf{Q}_1$, wave-vector of the 1-st volume grating

$\mathbf{q}$, wave-vector of surface grating
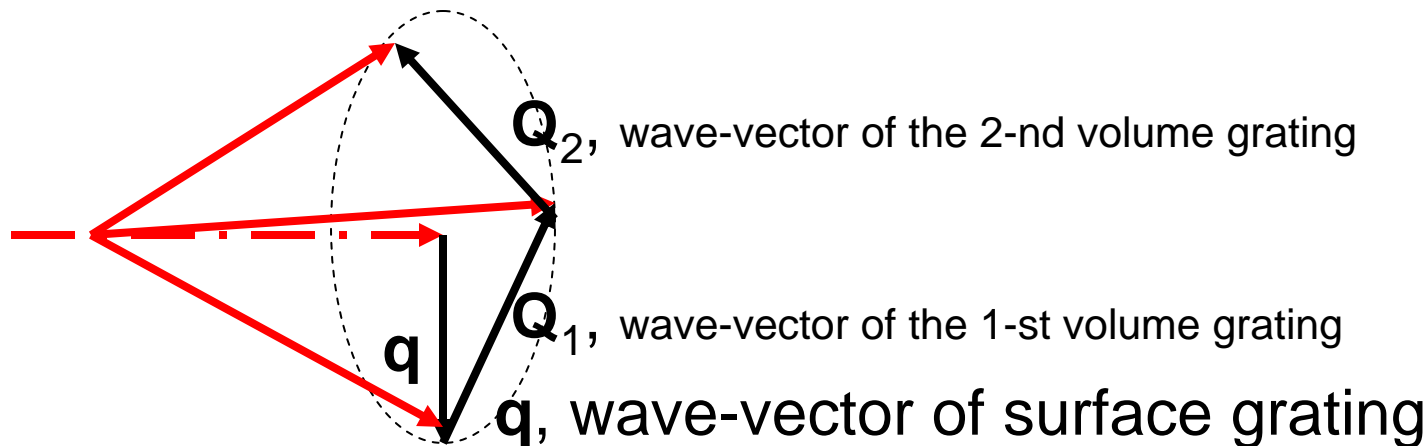
The best foreseeable scheme

The beam may be restored to the original direction by the second surface grating, like this:


or in a scheme with 2-d angular selection, where two volume gratings work between two surface gratings.

What was actually done

We used Photo-Thermo-Refractive process of recording volume phase holograms in special glass (developed at CREOL by Dr. Glebov and his team). Those holograms have diffraction efficiency better than 95%. They are extremely stable, even under 100 KW / cm^2 of true CW laser light.

We used surface reflecting grating instead of transmission one.
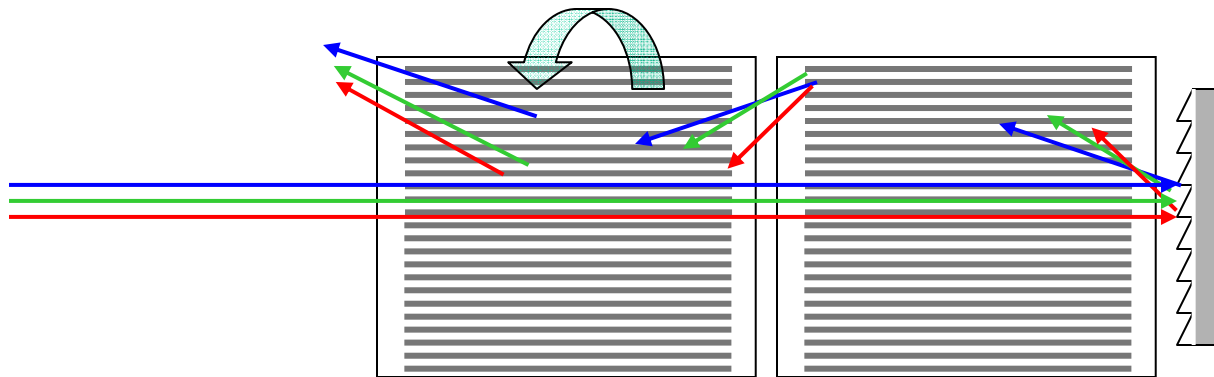
These two volume gratings had their **Q**-vectors perpendicular (I failed to draw it properly here).

Demonstration
of simultaneous 3-color
2-d angular selection
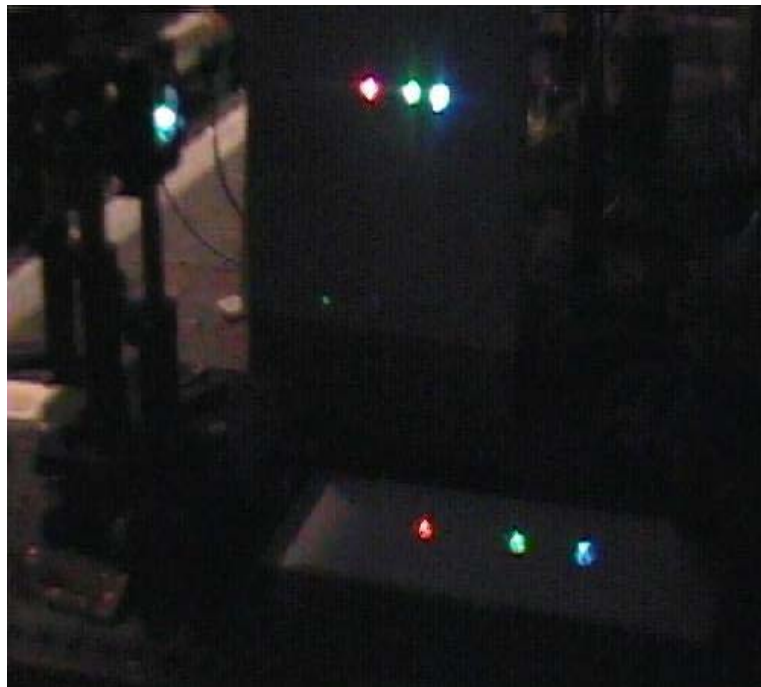
The beams diffracted on the first Bragg grating appear in the direction perpendicular to the diffraction plane of the surface grating (bottom part of the photo).

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CONCLUSION

1. **We invented the acronym ASADOG:**

   Angular Selective Achromatic Diffraction Optical Grating.

2. **We suggested the scheme of ASADOG for angular selection in one or in both angular directions.**

3. **We have actually implemented 1-d and 2-d ASADOGs.**

4. **Photo-Thermo-Refractive volume glass holograms were specially recorded for that.**

5. **We are still looking for potential applications.**